THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

Radiation Laboratory

EC-135 SURFACE FIELD MEASUREMENT AT OBLIQUE INCIDENCE

By

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1. INTRODUCTION

This is the third of the Task Reports on the Contract F29601-76-C-0004 entitled, "Aircraft Scale Model Measurements and Scaling Verification". This report presents the measured surface currents on model EC-135 aircraft in the presence of perfectly conducting ground plane illuminated at 18 degrees from horizontal. The polarization, i.e., incident electric vector, is horizontal and the models were mounted on the metal sheet so that the fuselage was always parallel to the incident electric field. There were no HF wires present on the models.

Both amplitude and phase data is presented and cover 1.385 to 35.1 MHz full scale frequency range.

2. MEASUREMENTS

2.1 Facility

To make these measurements, a 12 x 12 foot ground plane inclined at 18 degrees was constructed in our tapered anechoic chamber at the Willow Run facility. Figure 1 shows the geometry as observed from the side. In the area where the model is measured, a 4 x 12 foot 0.030 inch thick aluminum sheet is used. It is then extended toward the transmit antenna another 8 feet using a plywood surface covered with a 0.005 inch thick aluminum foil. To obtain a uniform "infinite sheet" field variation over the measurement area of the ground plane, special attention was given to the front and the rear edges of the structure. To reduce the front edge diffraction, the edge was burried in the chamber absorber and the sheet was partly covered on top with more absorber. For reduction of the rear edge effect, a 14 inch diameter cylinder covered with absorber was attached to the rear edge.

With this arrangement the surface current was measured along the ground plane in the direction of propagation to determine the purity of the resultant field.

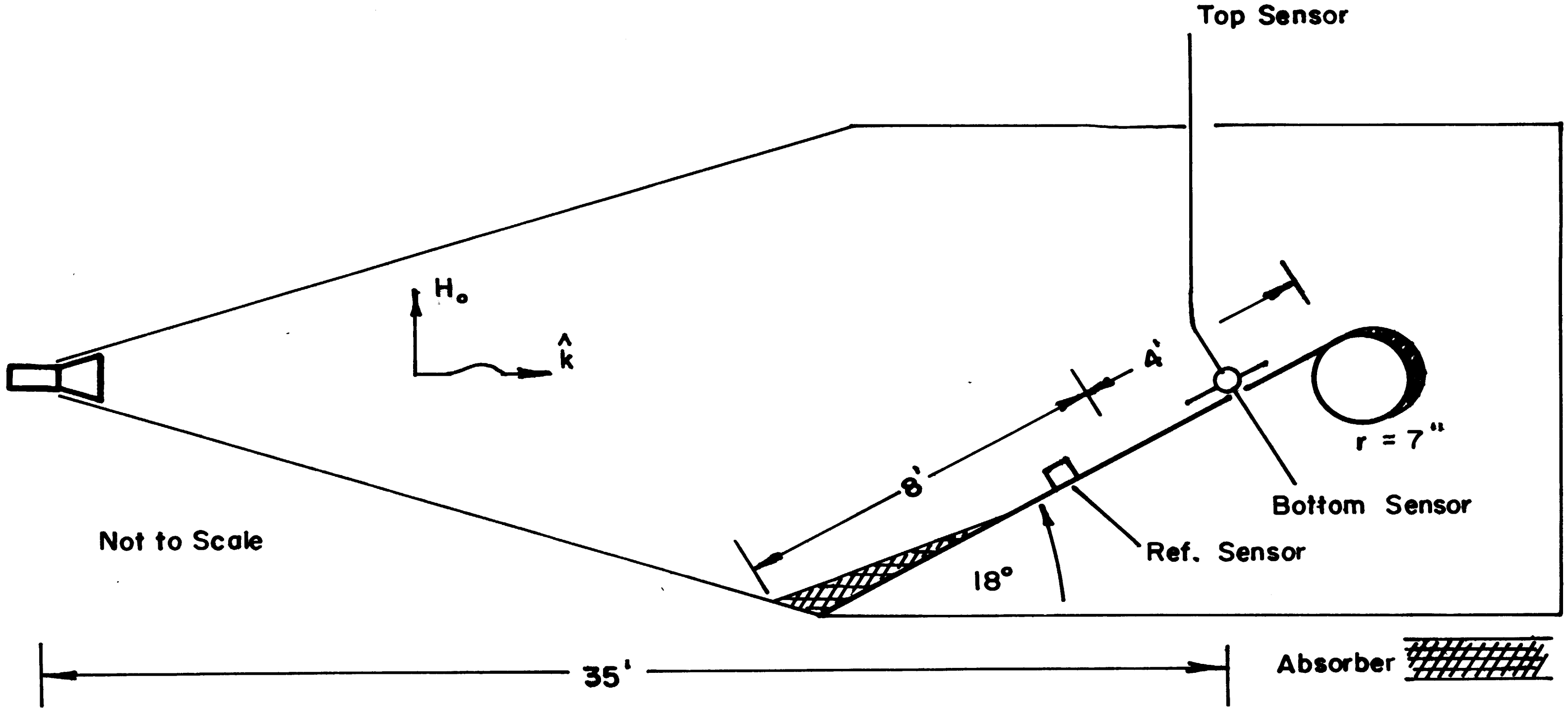


Figure 1. Implementation of the 18 degree ground plane.

To accommodate the MGL-8 (connector below) sensor, holes were drilled 5 cm apart in the ground plane over the span of 80 cm. Surface current was then recorded for each of these positions as the frequency was swept over 500 - 1,000 MHz range. Using the center hole data as the reference level, the data was reduced for 500 and 1,000 MHz frequencies and the results are shown in Figure 2. In each case, the variation is ± 0.5 dB, a value considered to be acceptable for the measurement presented. Due to limited time, plus that connector on the sensor broke and had to be returned to the Air Force for repairs, similar corresponding measurements were not made in the 2.0 - 4.0 GHz range. However, the past experience (supported by theoretical arguement) shows that as frequency increases, the absorber performance usually improves and hence we expect the field uniformity to be ± 0.5 dB or better in the 2.0 - 4.0 GHz range.

2.2 EC-135 Models and Measurements

The measurements for the data presented were made in two frequency bands and using four 707 scale model airplanes modified by adding refueling booms and styrofoam blocks underneath the wings and fuselage to provide appropriate ground-fuselage clearance. In 0.45 - 1.10 GHz band 1/325, 1/216, and 1/129 scale models were used, but in 2.0 - 4.0 GHz band 1/325, 1/216 and 1/114 models were used to get a higher full-scale frequency coverage.

Measurements were made at stations on each model designated by:

F400T, F1200T	top of the fuselage
F400B, F1200B	bottom of the fuselage
W600T(A), W600T(B)	top of the right and left wing respectively
W600B(A), W600B(B)	bottom of the right and left wing respectively

Figure 3 shows the locations of the stations used. The convention is the same as used in previous EC-135 measurements (Liepa, 1976) plus the identification of the right (wing A) and left (wing B) wings of the model as would be identified by a passenger sitting in an aircraft facing forward. In these measurements, the

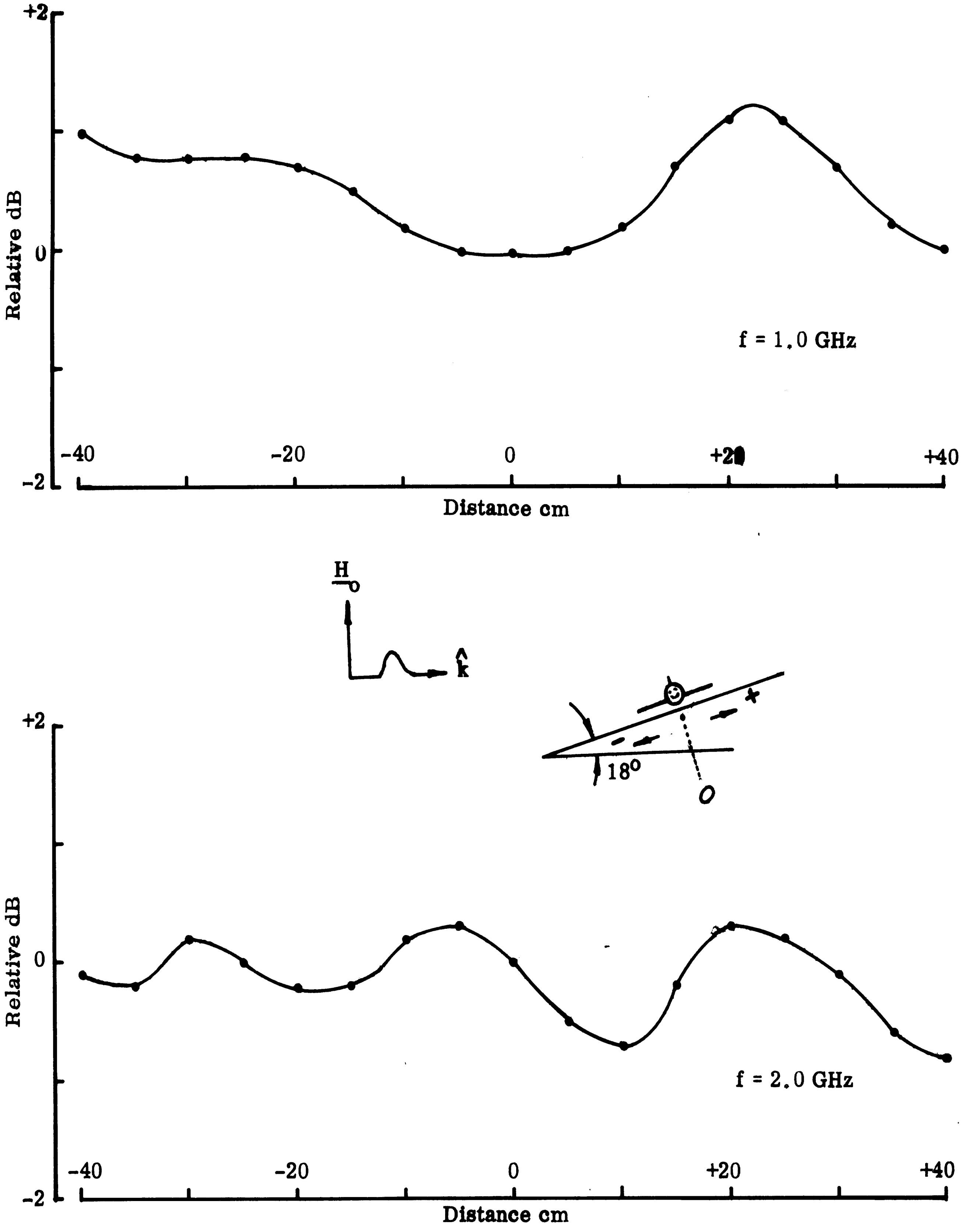
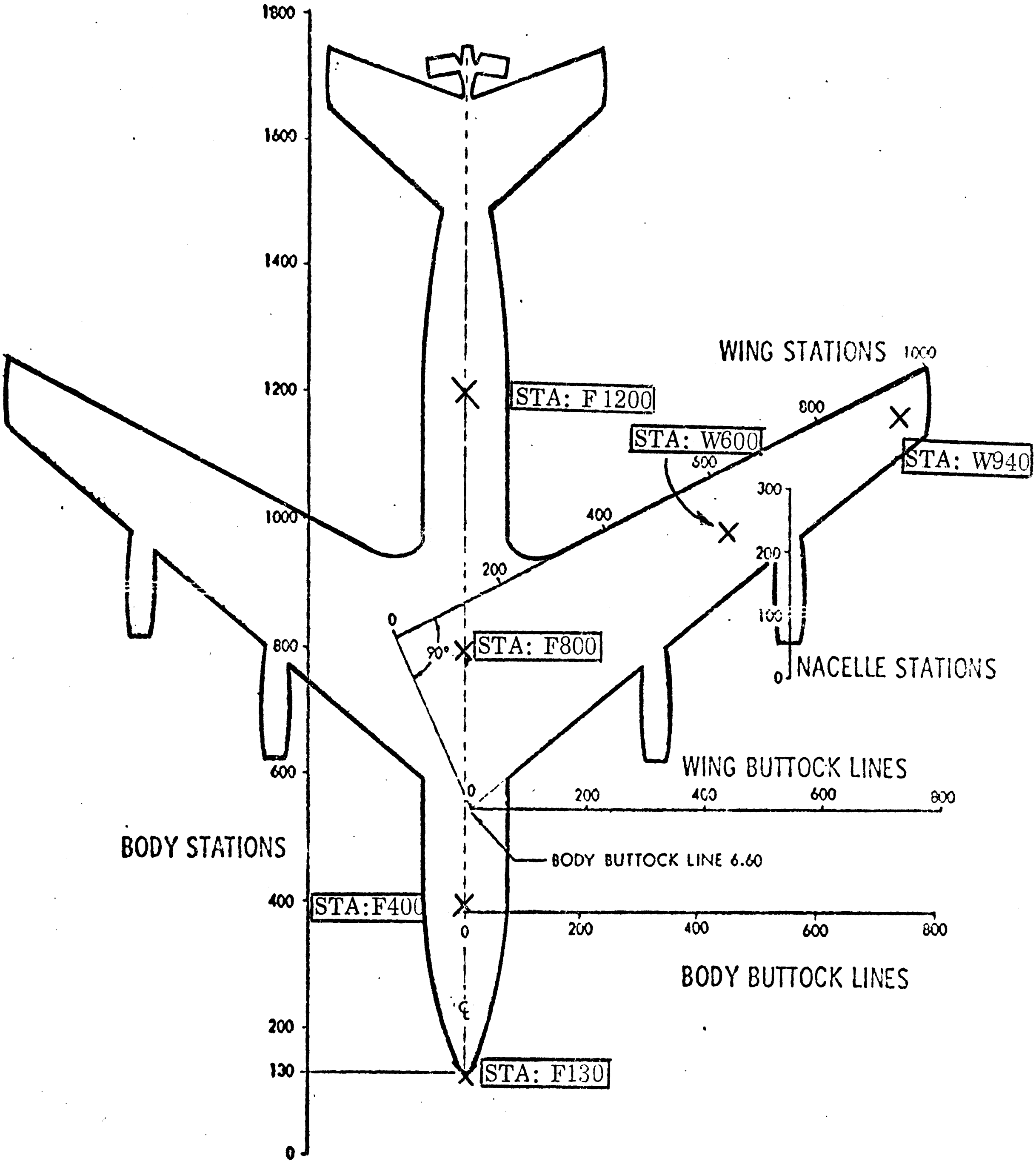


Figure 2. Measured Surface Current Distribution on the Ground Plane.



Note: Stations W600 and W940 are at mid-sections of the wing. Station W940 is located at the center of a circle tangent to the three wing edger.

Figure 3: EC-135 Aircraft Body Station Designation.

model was always placed with the fuselage perpendicular to the direction of the incident wave with the right wing(A) toward the excitation source. For both the top and bottom, the measurement procedure was similar. A model was placed on the ground plane with the station to be measured above the "0" position (see insert, Figure 2). The sensor was positioned extending either down from the ceiling for the top station measurements or up through the small hole in the ground plane for the bottom station measurements. With the loop just touching the surface of the model, a measurement was made; then after carefully removing the model without disturbing the sensor, the measurement was repeated for the calibration of the incident field. In measuring the fuselage current, both for the top and bottom, the loops were rotated so that the plane of the loop is perpendicular to the ground plane and passes through the center axis of the fuselage. In case of the wing current measurements, the loops were still perpendicular to the ground plane, but rotated ± 56 degrees, the estimated angle between the fuselage and the center of the wings. Such rotation does alter the loop response to the excitation field, and this is accounted for in the subsequent data reduction process (see equation 3.7).

3. THEORETICAL CONSIDERATION

Consider the geometry shown in Figure 4. A plane electromagnetic wave is incident at an angle θ upon a plane defined by x-z axis and is polarized such that the electric vector is parallel to the z-axis. For convenience, the phase of the incident wave is chosen such that at the origin the electric vector lies in direction of the positive z-axis and hence the wave can be represented by

$$\underline{E}^i = \hat{z} E_o e^{-ik(x\cos\theta + z\sin\theta)} . \qquad (3.1)$$

The $e^{+i\omega t}$ time connection is used throughout this presentation.

If the x-z plane is a perfectly conducting sheet, the field for $y \geq 0$, can be written as a sum of the direct and image waves, with the latter having a minus sign in order to satisfy the boundary condition $E_z \equiv 0$ on the surface. Thus

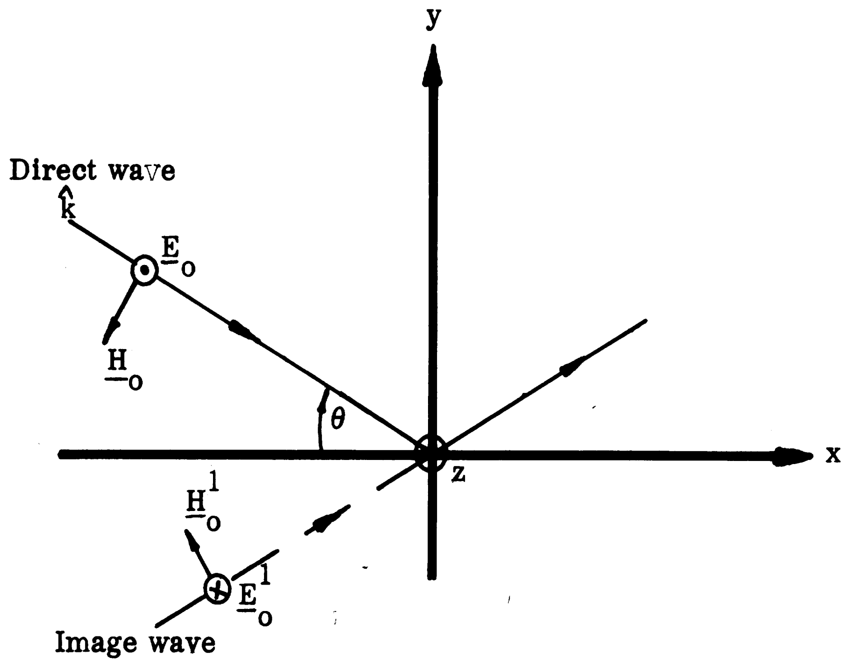


Figure 4. Ground Plane Geometry.

$$\underline{E} = \hat{z}E_o\left\{e^{-ik(x\cos\theta - y\sin\theta)} - e^{-ik(x\cos\theta + y\sin\theta)}\right\}$$

$$\underline{E} = \hat{z}E_o 2i\sin(ky\sin\theta)e^{-ikx\cos\theta}. \qquad (3.2)$$

The corresponding magnetic field can be obtained by applying $\nabla \times \underline{E} = -i\omega\mu\underline{H}$ to equation (3.2) or can be written directly from the diagram as was done for the electric field. Either way then

$$\underline{H} = -2H_o e^{-ikx\cos\theta}\left\{\hat{x}\cos(ky\sin\theta)\cdot\sin\theta + \hat{y}i\sin(ky\sin\theta)\cdot\cos\theta\right\}, \qquad (3.3)$$

where $H_o = x_o E_o$ with $x_o = \sqrt{\mu_o/\epsilon_o}$.

Of specific interest is the plane case x=0. For a particular measurement, the aircraft model was positioned so that the station to be measured lied in the x=0 plane. In addition, the loop was oriented vertically, and hence would not respond to the H_y component of the magnetic field. Thus, from equation (3.3)

$$\underline{H} = -\hat{x}2H_o\cos(kh\sin\theta)\cdot\sin\theta \qquad (3.4)$$

where h is the distance from the ground plane to the point of the measurement. This equation now related the incident field H_o to the calibration measurement H(cal) measured at the same point in space where the model station would be located for the model measurement H(mod). In process of reduction of the data, first H(mod)/H(cal) is computed at all sampled frequencies and then renormalized to

$$H(mod)/H_o = H(mod)/H(cal)\; 2\cos(kh\sin\theta)\cdot\sin\theta. \qquad (3.5)$$

The negative sign that appears in equation (3.4) can be said to apply to both the H(mod) and H(cal) measurements and, hence cancells out in the equation (3.5).

To measure the "axial" currents on the wings, the sensor loop was rotated $\phi = \pm 56$ degrees, the estimated angle between the fuselage and the center of the wing. The H(cal) was measured with the loop in rotated position and, hence to include this situation, the equation (3.5) was multiplied by $\cos\phi$, i.e.,

$$H(mod)/H_o = H(mod)/H(cal) \; 2\cos(kh\sin\theta)\cdot\sin\theta\cos\phi. \qquad (3.6)$$

In the computer code, the equation was expressed in terms of more practical variables. Using $\theta = 18$ degrees, the inclination of the ground plane, the frequency in GHz and the h in cm,

$$H(mod)/H_o = H(mod)/H(cal) \; 0.61803\cos\phi\cdot\cos(0.06472fh) \qquad (3.7)$$

where the argument for the latter cos function is in radians. The equation (3.7) was used for reducing all measurement presented : for the fuselage stations we set $\phi = 0$ and for the wing measurements $\phi = \pm 56$ degrees. Of course, the sign has no effect, since $\cos(-x) = \cos x$.

4. DATA

4.1 Recording and Reduction

The analog signals representing the amplitude (dB) and phase were first recorded on dual channel x-y plotter. Calibration measurement was taken for every data measurement and given 8 stations, 2 frequency bands, and 3 different scale models, a total of 96 recordings were made.

For reduction of this data, a digital procedure was developed and used whereby the analog data was first digitized using Computek Tablet interfaced with a PDP-11 computer where the data was stored on the disc. From there, it was copied to MTS (The University of Michigan AMDAHL 470 V/6 machine) and further processed using codes based on formulations presented in Section 3. The reduced data was then plotted from MTS onto a desk-top digital plotter.

At present, processing of the data is in a continuous development. The present graphics code can plot only a single curve per page. We hope that soon we will have the program rewritten to present up to 6 curves per page, thus displaying the entire measured (full scale) frequency range on the same plot. The data presented here will be replotted and presented in the Final Report.

4.2 Presentation of Plots

There are a total of 96 plots of amplitude and phase data contained in this report. The plots are arranged by the measurement locations, first amplitude and followed by the phase data. The amplitude plots are H/H_o vs frequency where H_o is the incident magnetic field without the ground plane. The following table is supplied to help locate the particular station data.

STA	PLOT No.'s
F400T	1-12
F1200T	13-24
F400B	25-36
F1200B	37-48
W600T(A)	49-60
W600T(B)	61-72
W600B(A)	73-84
W600B(B)	85-96

One also will observe that on each plot in the upper right hand corner there is a somewhat abbreviated title used to identify the plots. The code used is

STA : W600B(A) 129 RAB 19 — File Number

W	600	B	(A)	129	R	A	B	19
W-wing F-fuselage		B-bottom T-top		Scale	Rockwell	Freq. A(.45-1.1GHz) Freq. B(2.-4.GHz)	B-bottom T-top	File Number

The digital data for these curves is presently stored on disc files on MTS and has also been copies on a 9-track Magnetic Tape, 6250 BPI. A copy of this tape can be provided to Air Force is needed.